3.6.4. Dynamic Maneuvering Position Accuracy

3.6.4.1. Purpose

The purpose of this test is to measure the dynamic maneuvering position accuracy of the GPS/INS, GPS alone and INS alone to isolate the effects of various types of aircraft maneuvers and to qualitatively assess the utility of the system as a navigation aid in the maneuvering environment.

3.6.4.2. General

Dynamic non-maneuvering position accuracy testing provided a baseline of accuracy which included the effects of strictly non-maneuvering flight. Using this baseline data, the aircraft will perform a series of maneuvers with space positioning data taken after each maneuver. The exact flight profile will have little effect upon the accuracy compared to the effects of maneuvering. For this reason, a single, laser tracker or theodolite array can be repeatedly used. A significant departure from the dynamic baseline data plot will be due to aircraft maneuvering. In this way, the effects of mission relatable maneuvering upon system accuracy will be isolated from other effects. Low acceleration roll, pitch (a loop maneuver will be used) and yaw maneuvers will be used to check for INS gimbal limits as well as attitudes where GPS coverage is significantly degraded. Airspeed limitations will be checked while accelerating from a slow airspeed to the airspeed limit of the aircraft. Roll, pitch, yaw and level turn maneuvers to the limits of the aircraft will be used to assess the effects of maneuvers in a single plane. Finally, rolling push-overs and pull-ups will be performed to the aircraft limits to check the effects of multi-axis maneuvers. Table VI shows the typical linear and angular dynamic limits for a notional GPS unit designed for use on a tactical platform [Ref. 10].

3.6.4.3. Instrumentation

A stop watch and data cards are required for this test, a voice recorder is optional. A properly instrumented range including highly accurate laser ranger or theodolite tracking is required. For the case where a laser ranger is used, a laser reflector array must be installed on the test aircraft.

3.6.4.4. Data Required

For the configuration where the GPS and INS are available and coupled, after

Table VI: Typical GPS Linear and Angular Dynamic Limits

	Linear Dynamics(1)	Angular Dynamics
Velocity (m/sec) or Rate (rad/sec)(2)	1,200	yaw ± 1.0
		pitch ± 1.0
		roll ± 5.5
Acceleration (m/sec^2 or rad/sec^2)(2)	90	yaw ± 3.0
		pitch ± 6.0
		roll ± 17.5
jerk (m/sec)	100	not usually specified

(1) Any linear axis.
(2) As appropriate.

recording the initialization and alignment data, record the displayed latitude and longitude as a navigation mode is selected. At each laser ranger or theodolite flyover point, record the elapsed time, altitude, GPS/INS displayed latitude and longitude, satellites used, satellite quality numbers, total fix quality number and laser or theodolite calculated latitude and longitude. After the taxi back to the hangar, record the surveyed parking location, elapsed time and GPS/INS displayed latitude and longitude. Throughout the flight, record as notes on the data cards, any INS or GPS system alerts, along with the elapsed time of occurrence. Record qualitative comments concerning the utility of the GPS/INS in navigating to and from the test area as well as during the maneuvers.

Record the same data for the GPS-alone test condition, deleting the INS alerts. Repeat both tests without the P code installed. When using the INS alone, record the data described in the INS test procedures provided earlier.

3.6.4.5. Procedure

During preflight planning, choose a point within range of a laser tracker or within the operating area of a theodolite array that allows low and medium altitude maneuvering as well as supersonic flight at low and medium altitudes in the case of a supersonic test aircraft. Choose an initial airspeed that conserves fuel. Record GPS/INS and space positioning data upon arriving within the test area as described in the dynamic non-maneuvering position accuracy section. Climb to a moderately low altitude in the case of an attack aircraft and a medium altitude in the case of a fighter aircraft and perform a maximum power acceleration to the limit airspeed or mach number of the aircraft. A shallow dive can be used to expedite the maneuver as long as it can be safely performed at the chosen altitude. When a dive is used, an initial altitude above the test altitude should be chosen. Generally, the rate of descent should never exceed 1/2 of the aircraft altitude for safety purposes.

Following the acceleration, decelerate to a good maneuvering speed while performing a 1.5 g or less turn, return to the range area and again record GPS/INS and space positioning data. Next, climb to a medium low altitude and perform a constant 3 g, 360° turn. Use the best maneuvering airspeed, or the cornering airspeed, for the test. The cornering airspeed will be available from the aircraft operating manual. Return to the range area and again collect the GPS/INS and space positioning data. Repeat at 5 g and then at the maximum aircraft level g. For the fighter aircraft test, perform the maximum g test at a medium altitude. Next, climb to a medium low altitude, set a good maneuvering airspeed and perform an aileron roll at 1/4 stick deflection. Again collect the GPS/INS and space positioning data. Repeat at 1/2 stick deflection and then at full stick deflection or at the aircraft roll limit, whichever is greater. Again at a medium low altitude provide a step rudder input at 1/4 and 1/2 rudder deflection and finally at either full rudder deflection or the aircraft rudder input limit. Collect the same data between each input.

Finally, climb to a medium low altitude and perform a series of rolling push-overs and pull-ups, increasing the g to the aircraft limits. After reaching the aircraft limit, collect the same data. Return to the home airfield. Before shut down, record the shut-down spot surveyed latitude and longitude, the elapsed time and the displayed latitude and longitude. During the entire flight, watch for GPS and INS system discretes and record them as notes along with the time of occurrence. Thoroughly investigate all failure discretes after the flight. In addition, qualitatively evaluate the INS controls, steering cues, displays and accuracy as an aid for finding the flyover points in the maneuvering environment.

Repeat the test for the case where the GPS alone is used. The entire flight may be performed in the vicinity of a space positioning range. Repeated laser ranger or theodolite fixes at 5 to 15-minute intervals are required. Repeat the first two tests without the P code installed.

For the condition where the INS is used alone, perform the test as outlined in the INS test procedure section.

3.6.4.6. Data Analysis and Presentation

Subtract the coupled GPS/INS displayed latitude and longitude from the surveyed point latitude and longitude or precise space positioning derived latitude and longitude, as appropriate. Convert the latitude and longitude difference to nm using equation (21). Plot the data as latitude and longitude error versus elapsed time. Annotate the plots with all the maneuvers performed before each point was recorded as well as any system alerts or changes in the GPS satellites in use. Check the plot for any significant change in the slope of the error plot and relate any changes to the effect these maneuvers have upon GPS/INS accuracy. Further relate the error to the loss of accuracy during mission relatable ACM for fighters and evasive maneuvering inbound to the target for attack aircraft.

Since the time dependent errors of the INS are not easily seen in the coupled system, it is also useful to develop a scatterplot as defined in the OMEGA section to highlight any errors caused by the position fixing GPS receiver.

If system alerts are noted during the flight, check for significant changes in the error rate curve following the time the alert is noted. Thoroughly investigate any GPS or INS alerts after the flight. Alerts that imply degraded accuracy and do not result in a change on the error curve or cannot be associated with a system failure should be related to the possibility of unnecessarily aborted sorties (false alarms). Relate the utility of the GPS/INS displays/controls, steering cues and integration within the aircraft to the usefulness of the INS as an aid for navigating to waypoints, the target position and later returning to the home airfield.

Analyze the recorded satellites and quality numbers for changes and drops, checking for corresponding degradation in the navigation accuracy. If the accuracy is degraded beyond the necessary accuracy, follow up with an investigation of the satellite geometry and the appropriateness of the individual satellite selection.

Repeat the procedure for the case of the GPS alone. The time base plot is not normally used for a position fixing system, however it may be useful to highlight the effects of satellite swaps and drop outs and of the individual maneuvers. Relate the performance to the necessity to perform the mission after the INS has failed or after an alert launch that did not allow for the alignment of the INS.

Analyze the data derived with the P code missing in the same fashion as the two previous sets of data. Relate the data to the necessity to perform the mission after the P code is dropped or when it is not available due to operational constraints.

Reduce and analyze the INS-alone data identically to the processes outlined in the INS test procedures.

3.6.4.7. Data Cards

Sample data cards are provided as card 52.

CARD NUMBER ___ TIME ____ PRIORITY L/M/H

DYNAMIC MANEUVERING POSITION ACCURACY

[AFTER PERFORMING THE INITIALIZATION AND ALIGNMENT TEST, SELECT A NAVIGATION MODE. START THE STOP WATCH AND RECORD THE LATITUDE AND LONGITUDE. AFTER TAKEOFF, SET ___ KIAS, CLIMB TO _____ FEET MSL AND ASSUME NAVIGATION TO THE RANGE TAKING DATA ONCE THERE. PERFORM EACH MANEUVER AND BETWEEN EACH TAKE A DATA POINT. RECORD AS NOTES SYSTEM ALERTS AS WELL AS GPS SATELLITE CHANGES. RECORD QUALITATIVE COMMENTS CONCERNING SYSTEM UTILITY FOR NAVIGATION DURING MANEUVERING FLIGHT OF DISPLAYS/CONTROLS, STEERING CUES AND NAVIGATION ACCURACY. RECORD DATA BEFORE SHUTDOWN.]

SURVEYED ALIGNMENT LOCATION __________ __________

DISPLAYED WHEN SELECTED _________ __________

CONFIGURATION: GPS ON ___ INS ON ___ BOTH ON ___

P CODE: YES / NO

SATELLITES IN USE/QUALITY NUMBERS:

TOTAL FIX QUALITY NUMBER ______

NOTES:

Card 52: Dynamic Maneuvering Position Accuracy Data Cards

CARD NUMBER _____

DYNAMIC MANEUVERING POSITION ACCURACY

TRANSIT AIRSPEED ___ KIAS

TRANSIT ALTITUDE _____ FEET MSL

OPTIMUM LOCATION FOR COLLECTING POSITIONING DATA __________ __________

MAN-EUVER	ALT/AIR-SPEED (FT MSL /KIAS)	TIME/ FLY-OVER ALT (FT MSL)	DISPLAYED/ RANGE DERIVED POSITION AND ALT (FT)	SATELLITE/ QUALITY NUMBERS	TOTAL FIX QUAL NUM-BER	NOTES:
INITIAL FLYOVER						
MAX LEVEL ACCEL						
LEVEL TURN 3G						
LEVEL TURN 5G						
LEVEL TURN _G						

Card 52: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

DYNAMIC MANEUVERING POSITION ACCURACY

MAN-EUVER	ALT/AIR-SPEED (FT MSL /KIAS)	TIME/ FLY-OVER ALT (FT MSL)	DISPLAYED/ RANGE DERIVED POSITION AND ALT (FT)	SATELLITE/ QUALITY NUMBERS	TOTAL FIX QUAL NUM-BER	NOTES:
1/4 STICK ROLL						
1/2 STICK ROLL						
FULL STICK ROLL						
1/4 RUDDER						
1/2 RUDDER						
FULL RUDDER						

Card 52: Dynamic Maneuvering Position Accuracy Data Cards (Continued)

CARD NUMBER _____

DYNAMIC MANEUVERING POSITION ACCURACY

MAN-EUVER	ALT/AIR-SPEED (FT MSL /KIAS)	TIME/ FLY-OVER ALT (FT MSL)	DISPLAYED/ RANGE DERIVED POSITION AND ALT (FT)	SATELLITE/ QUALITY NUMBERS	TOTAL FIX QUAL NUM-BER	NOTES:
ROLLING PUSH-OVERS/ PULL-UPS						

SURVEYED SHUTDOWN LOCATION __________ __________

ELAPSED TIME AT SHUT DOWN _____

DISPLAYED AT SHUTDOWN __________ __________

QUALITATIVE COMMENTS CONCERNING UTILITY DURING MANEUVERING FLIGHT OF NAVIGATION DISPLAYS/CONTROLS:

GPS/INS STEERING CUES:

MANEUVERING ACCURACY:

Card 52: Dynamic Maneuvering Position Accuracy Data Cards (Continued)